# 80i-kW

## CURRENT/POWER PROBE

## Instruction Manual

FLUKE

# 80i-kW

*CURRENT/POWER PROBE*

# Instruction Manual

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## Section 1
# Introduction and Specifications

### DESCRIPTION

The Fluke 80i-kW Current/Power Probe is a battery-powered, clamp-on, multimeter accessory that measures dc current, ac current, and ac power. The probe has two movable jaws activated by a trigger mechanism located in the handle. Each jaw contains half of a magnetic core. The jaws clamp around a conductor, allowing measurements to be made without breaking the circuit.

The 80i-kW uses two Hall devices, which drive an amplifier circuit that generates a switch-selectable output of 1 mV per amp, or 1 mV per kilowatt. The Hall devices are located in gaps of the magnetic core. When the current function is selected, the Hall devices act as magnetic field sensors.

The kilowatt function uses the same Hall devices, configured into analog multiplier circuits. The voltage input signal from the load is transformer-coupled to one side of the Hall devices. The output becomes the cross product multiplication of the load voltage times the load current, which is proportional to true load power.

This method takes into account the phase angle and waveform distortion of both voltage and current and provides good performance over a wide range of input signals.

A ZERO control is used to offset core magnetization to improve accuracy of low-level dc current and kilowatt measurements.

## CARRYING CASE

The carrying case, supplied with the 80i-kW, provides protection for the probe during transit. It has additional compartments for a multimeter (not included), voltage test leads (included), a 9V battery (included), the Instruction Manual (included), and Quick Reference Guide (included). The carrying case and contents are shown in Figure 1-1.

The multimeter compartment in the center of the case accommodates a range of multimeter sizes. The end of this compartment (opposite the finger hole) contains a removable section. For small multimeters, this section is left in; for larger units, the section can be removed.

The compartment nearest the handle holds temperature-measuring accessories, such as the Fluke 80T-150U temperature probe, or the 80TK thermocouple module and one or more thermocouple probes.

When fully outfitted, the carrying case becomes a tool kit for industrial plant maintenance and/or energy management applications.

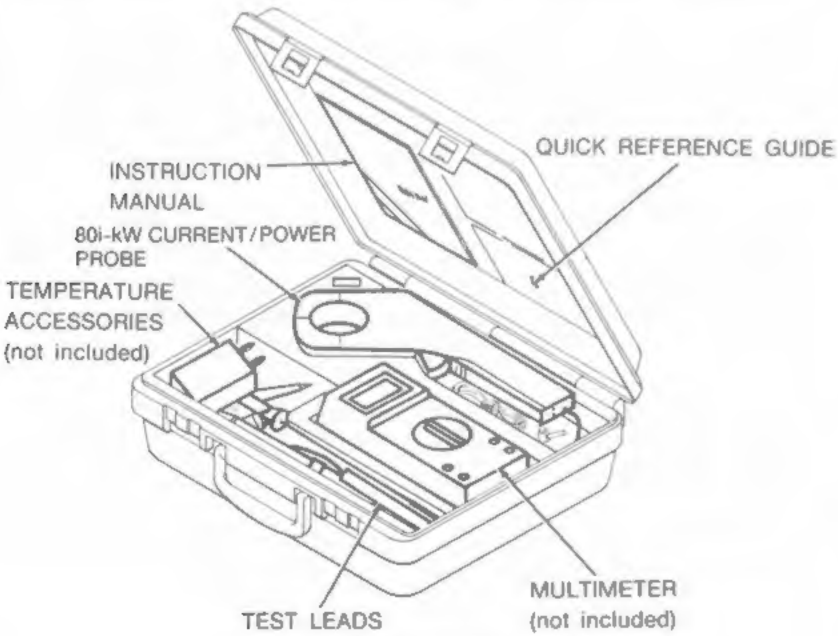



**Figure 1-1. 80i-kW with Carrying Case**





## APPLICATIONS

The 80i-kW is suitable for a wide variety of applications involving the construction and maintenance of ac and dc electrical distribution systems. The probe is also suitable for energy management surveys of single-phase and 3-phase ac power systems.

Since the probe has a voltage output, it may be connected directly to multimeters, voltmeters, oscilloscopes, data loggers, and other voltage indicating devices. Consult the compatibility section of this manual for impedance loading and connector interfacing considerations.

The probe and voltmeter combination can make the measurements necessary to determine the power factor of single-phase and 3-phase loads. See Section 2 of this manual for more information.

## SPECIFICATIONS

Refer to Table 1-1 for 80i-kW electrical and general specifications.

## VOLTMETER COMPATIBILITY

The 80i-kW is compatible with any voltmeter, multimeter, or other voltage-measuring instrument that has the following features:

- Input jacks that accept Fluke safety-designed shrouded banana plugs spaced at ¾ inch apart.
- Input impedance > 1 MΩ, 100 pf. (See load impedance specifications for operation with lower impedance instruments.)
- Range and resolution capable of displaying 1 mV of output per amp or kilowatt of measured input.
- Voltmeter accuracy (uncertainty) of 0.3% or better to take full advantage of the accuracy of the probe.

Since the output signal of the probe is electrically isolated from both the current and voltage being measured, the output cable may be connected to either a grounded or floating input. (See specifications for output signal isolation.)

Table 1-1. 80i-kW Specifications

**ELECTRICAL**

**DC Current**

**Range:** 1 to 1300A dc

**Accuracy** (uncertainty) (see note): ±% of reading, 1 year

| | |
|---|---|
| 1 to 700A | 2% + 2A |
| 700 to 1000A | 3% |
| 1000 to 1300A | 4% typical |

**AC Current**

Range: 1 to 1000A ac or ac + dc

Accuracy (uncertainty) (see note below): ±% of reading, 1 year

| | dc to 62 Hz | 62 Hz to 440 Hz |
|---|---|---|
| 1 to 500A | 2% + 2A | 6% + 2A |
| 500 to 700A | 3% | 7% |
| 700 to 1000A | 6% | 8% typical |

**AC Power**

Range: 0.5 to 330 kW ac (90 to 660V ac, 1 to 500A ac)

Accuracy (uncertainty): ±% of reading, 1 year

| 48 to 62 Hz | 390 to 410 Hz |
|---|---|
| 3.5% + 0.5 kW (Power Factor > 0.5) | 4% + 0.5 kW (Power Factor > 0.9) |

NOTE

18 to 28°C (64 to 82°F), Conductor centered, ZERO adjustment prior to measurement (dc and kW only). See Section 2 for accuracy enhancement methods.

| | |
|---|---|
| Output Signal Scaling: | 1 mV per amp or 1 mV per kW. (Gives correct decimal for readout in amps or kW on digital multimeters with mV scale.) |
| Load Impedance: | >1MΩ, 100 pf for rated accuracy. The probe can drive lower impedances, but the accuracy is reduced because the probe output impedance is approximately 1kΩ. |





Table 1-1. 80i-kW Specifications (cont)

| | |
|---|---|
| Frequency Response: | -3 dB at 3.2 kHz typical |
| Crest Factor: | Rated accuracy for waveforms with crest factor <3.0. |
| Conductor Off Center: | <1.5% change with 0.63 inch (16 mm) or larger diameter cable typical |
| Adjacent Conductor Current: | <0.015 A/A typical |
| Working Voltage: | 660V rms maximum at current or voltage inputs |
| Output Signal Isolation: | Signals on the output cable are isolated from the current input by magnetic coupling and are isolated from the voltage input (kW mode) by transformer coupling. The output cable may be connected directly to a grounded input or floated to 42V dc or 30V ac maximum from earth ground. |
| High Frequency Heating Limitation: | 5 minutes maximum operating time when current-frequency product exceeds 120A-kHz. |
| Impedance of Voltage Input: | 380kΩ nominal |
| **GENERAL** | |
| **Operating Temperature Range:** | 0 to 50°C (32 to 122°F)<br>Usable to -10°C (5°F) |
| **Storage Temperature Range:** | -40 to 60°C (-40 to 140°F) |
| **Temperature Coefficient:** | 0.06 x specification per °C<br>(0 to 18°C, 28 to 50°C) |
| **Relative Humidity:** | 95%±5% (11 to 30°C)<br>75%±5% (31 to 40°C)<br>45%±5% (41 to 50°C) |
| **Aperture Size:** | Oval, 2-7/8 inch x 2-3/8 inch (73 mm x 60 mm) |
| **Battery:** | Type: 9V, NEDA, 1604A<br>Life: 100 hours typical for alkaline Low Indication: Power on LED indicator turns off when battery voltage falls below lower operating limit. |
| **Output Connector:** | Dual male banana with Fluke, safety-designed shrouds, 3/4 inch spacing |

**Table 1-1. 80i-kW Specifications (cont)**

| | |
|---|---|
| **Voltage Input Connectors:** | Male banana which accept female banana connectors with safety designed shrouds. |
| **Voltage Input Test Leads:** | Special voltage test leads and detachable safety alligator clips are provided. The test leads have shrouded female banana jacks on one end and shrouded male banana jacks on the opposite end. |
| **Size:** | Width: 1½ inch (38 mm) nominal<br>Overall Length: 11¾ inch (298 mm) nominal |
| **Weight:** | 1 lb. 13 oz. (822 grams) nominal |
| **Safety:** | Protection Class II as defined in IEC 348 and ANSI C 39.5 |



# Section 2
# Operating Instructions

## OPERATOR SAFETY

Read this safety information carefully before attempting to operate or service the 80i-kW.

*NOTE*

*The instruction manual symbol "⚠" appears on the control panel label of the probe. The symbol refers the operator to additional information contained in this instruction manual which is also identified by the symbol "⚠" appearing in the left-hand margin of the page.*

### Safety Rules

The following safety rules must be followed during operation or maintenance of the 80i-kW. Strict adherence of these rules is essential for safe operation. John Fluke Manufacturing Co., Inc. assumes no liability for failure to comply with these rules.

⚠ • Do not clamp the probe jaws around bare conductors or conductors with voltages exceeding 660V dc or rms ac.

⚠ • Do not connect the voltage input test leads to terminals that have voltages exceeding 660V ac.

⚠ • Do not exceed the 5-minute time limitation when measuring current where the A-kHz product is greater then 120A-kHz.

- Inspect the test leads, safety alligator clips, output lead, probe body, and core hinge insulator for damage prior to use. Do not use if damage is detected.
- Do not operate the probe in an explosive environment.
- Do not attempt to make measurements on live high-energy circuits unless another person, trained in first aid is present.
- Do not make unauthorized modifications to any part of the probe or its accessories.
- Read the operating instructions before use and observe the safety messages contained in the instructions.

### Safety Messages

In this instruction manual:

| | |
|---|---|
| "DANGER" | identifies a severe and immediately accessible personnel hazard that can cause death or injury. |
| "WARNING" | identifies a personnel hazard. It alerts the operator about a condition or procedure that could cause death or injury. |
| "CAUTION" | identifies an equipment hazard. It alerts the operator to a condition or procedure that could cause damage or destruction to the equipment. |

### Symbols

The symbols used in Table 2-1 are used to denote functions and conditions pertaining to probe operation.

## OPERATING FEATURES

The operating features of the 80i-kW are illustrated in Figure 2-1. Table 2-2 describes each item.





**Table 2-1. Symbols Used with the 80i-kW**

| SYMBOL | SYMBOL NAME | SYMBOL DEFINITION |
|---|---|---|
| ⚠ | Instruction Manual Symbol | Alerts the operator to refer to the instruction manual for important additional information |
| ⧈ | Double Insulation Symbol | Indicates that the equipment meets the double insulation standards set forth in IEC 348 |
| ∼ | ac | Indicates that the signal is alternating current or voltage |
| ⎓ | dc | Indicates that the signal is direct current or voltage |
| ⎓∼ | ac or dc | Indicates that the signal is either ac or dc |

**Table 2-2. Controls, Indicators and Connectors (See Fig 2-1)**

| ITEM | NAME | DESCRIPTION |
|---|---|---|
| 1 | Common Tab | Identifies the Common or Low side of the output connector |
| 2 | Output Cable | Connects the probe's output signal to the input of the multimeter or indicating device. |
| 3 | Zero Adjust | Used to zero the probe's output voltage signal before taking dc current or kilowatt readings. |
| 4 | Function Switch | Slide switch used to turn probe's battery power on or off and to select between AMP or kW functions. |
| 5 | Power On Indicator | Red LED indicates power is on and battery voltage is within operating limits. LED goes off when battery voltage falls below lower operating limit. |

Table 2-2 Controls, Indicators and Connectors (cont)

| ITEM | NAME | DESCRIPTION |
|---|---|---|
| 6 | Current Direction Arrow | When the "AMP" function is selected the arrow identifies the direction of conventional dc current that will generate a positive output signal. In the "kW" function, a positive output signal is generated when the arrow points in the direction of the flow of power, i.e., from the supply to the load. This assumes that the voltage connections to the load are installed with the correct polarity |
| 7 | Core Hinge Insulator | Mylar insulation strip. Prevents metallic parts of core from making electrical contact with foreign objects. |
| 8 | Aperture | Current being measured must pass through the aperture |
| 9 | Core Closure | The magnetic core pieces come together at this point. Proper seating of these parts is absolutely essential for accurate measurements |
| 10 | Jaws | The movable jaws open up to surround the conductor(s) when current is measured |
| 11 | Jaw Trigger | When this control is pressed, both jaw pieces open simultaneously |
| 12 | Battery Door | This sliding door allows access to the battery compartment. The serial number is located on the underside of the door |
| 13 | Voltage Input Connectors | Connection point for voltage signal from the load. Used in kW mode only. The connectors are male and are designed to accept the female (banded) end of the supplied special voltage test leads |
| 14 | Voltage Test Leads | Special test leads for connecting load voltage signal to probe's voltage input connectors. Used in kW mode only. Leads have shrouded female connectors on one end which mate with probe's male input connectors. The leads have an identification band near the female end. The opposite ends have shrouded male banana plugs that connect to the safety alligator clips. Replacement leads are available from Fluke Parts Department. Ask for part number 845115 |





Table 2-2 Controls, Indicators and Connectors (cont)

| ITEM | NAME | DESCRIPTION |
|---|---|---|
| 15 | Safety Alligator Clips | Connect to male end of voltage test leads. Used to grip load voltage test points in "kW" mode only. Replacements available as part of TL20 test lead set or as individual parts from Fluke Parts Department. Ask for part number 927582 (Red) or part number 927579 (Black) |
| 16 | Voltage Connection to Load | Connection point for load voltage signal. Used in "kW" mode |

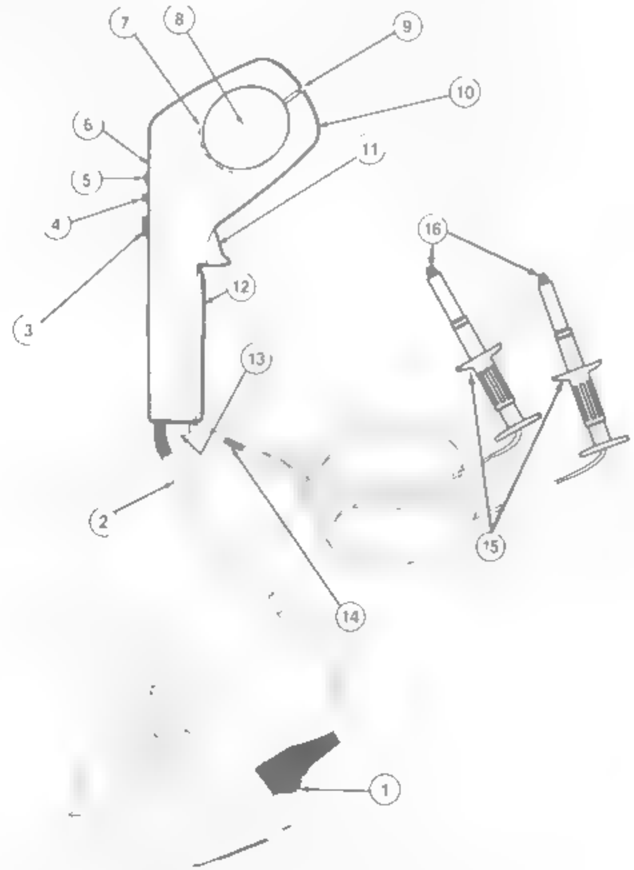



Figure 2-1. Operating Features of the 80i-kW (See Table 2-2)

## MEASUREMENT PROCEDURES

### Measuring DC Current (Amps ⎓)

*NOTE*

*Read the "OPERATOR SAFETY" information beginning on page 2-1 before attempting measurements.*

1. Connect the probe output cable to the voltmeter input and turn the voltmeter on as shown in Figure 2-2. (Observe polarity on output cable.)
2. Select the dc mV ⎓ function and a range capable of displaying 10 mV or more.
3. Set the probe function switch to AMPS.
4. Adjust the ZERO control on the probe until the voltmeter reads as close as possible to 0.0 mV.
5. Select a range or voltmeter capable of displaying the expected value (1 mV ⎓ per amp ⎓)

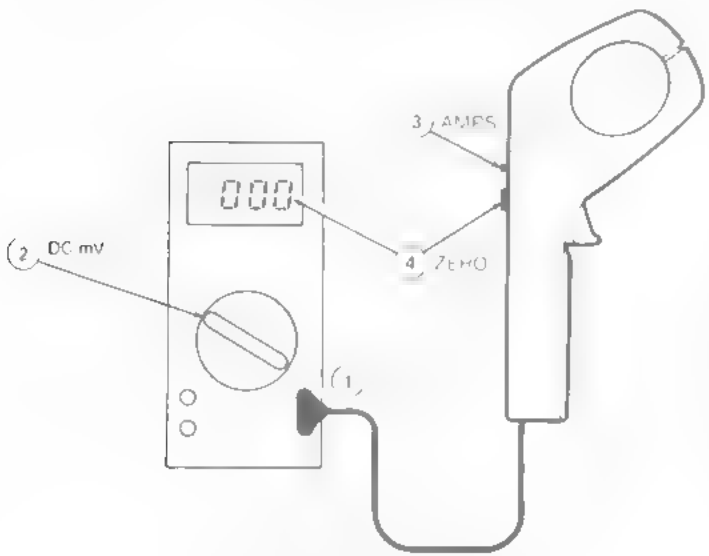



Figure 2-2. DC Zero Adjustment





6. Squeeze the jaw trigger and clamp the jaws around the conductor to be measured. Read the measured value in the voltmeter display. The jaws must be completely closed for a proper reading. Best accuracy is obtained when the conductor is centered within the jaw aperture. Figure 2-3 illustrates the correct way to measure dc current.

**WARNING**

**TO AVOID ELECTRIC SHOCK OR EQUIPMENT DAMAGE, DO NOT USE THE PROBE ON BARE CONDUCTORS.**

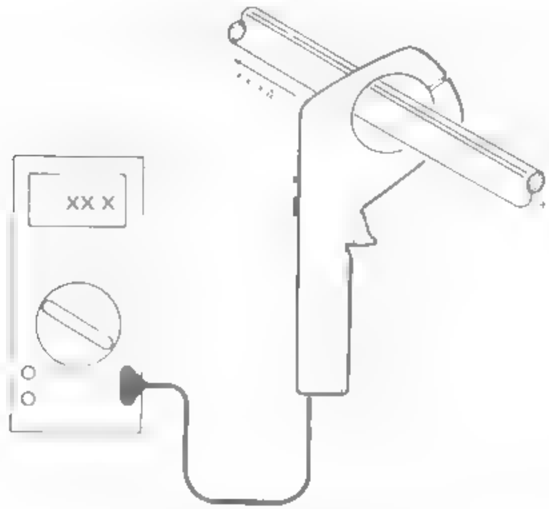



Figure 2-3. Measuring DC Current

*NOTE*

*When you are making low level measurements below 5A dc, accuracy can be improved by performing the dc ZERO adjustment procedure before each measurement. It is also advisable to check the ZERO adjustment if the current being measured has undergone a large change, i.e., from 100A to 1A, or if the measured current has changed polarity.*

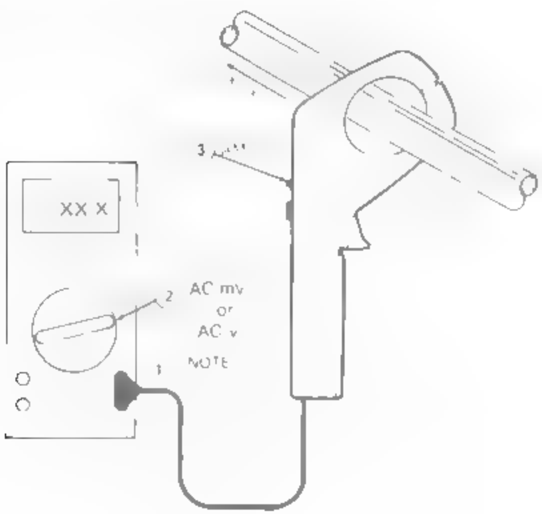
## Measuring AC Current (Amps~)

*NOTE*

*Read the "OPERATOR SAFETY" information beginning on page 2-1 before attempting measurements.*

**WARNING**

**TO AVOID ELECTRIC SHOCK OR EQUIPMENT DAMAGE, DO NOT USE THE PROBE ON BARE CONDUCTORS**




*NOTE[1]*

*When using AC V~ range, shift the decimal 3 places to the right for the correct reading in amps.*

Figure 2-4. Measuring AC Current





1. Connect the probe output cable to the voltmeter input and turn the voltmeter on. (Observe polarity on the output cable.)

*NOTE*

*If the voltmeter is dc coupled on the ac function, perform steps 2, 3, and 4 of the dc ZERO adjustment procedure (Figure 2-2) before proceeding to the next step*

2. Select the AC V~ function and a voltage range capable of displaying the expected value (1 mV~ per amp ~).

3. Squeeze the jaw trigger, and clamp the jaws around the conductor to be measured Read the measured value in the voltmeter display. The jaws must be completely closed for a proper reading. Best accuracy is obtained when the conductor is centered within the jaw aperture.

## Measuring AC Power (kW~)

*NOTE*

*Read the "OPERATOR SAFETY" information beginning on page 2-1 before attempting measurements.*

1. Connect the probe output cable to the voltmeter input. Observe the polarity on the output cable.

2. Turn the voltmeter on and select the dc mV ⎓ function. Choose a range capable of displaying 10 mV or more

3. Set the probe function switch to kW. Observe that the power LED is on.

4. Install the probe's voltage test leads with safety alligator clips into the voltage input connectors located at the base of the handle. Carefully observe the color-coded polarity markings on the probe.

*NOTE*

*The connections described in the next step apply to single phase 2-wire measurements only. For multi phase systems individual phase measurements are taken and the results are added (refer to the diagrams in Figure 2-7).*

5. Connect the red lead to the line side of the load voltage.

6. Connect the black lead to the neutral side of the load voltage.

7. Adjust the ZERO control on the probe until voltmeter reads as close as possible to 0.0 mV (See Figure 2-5.)

8. Select a dc range on the voltmeter capable of displaying the expected value (1 mV dc ⎓ per kW ac~).

*NOTE*

*Make sure that the voltmeter function remains in dc when measuring ac power.*

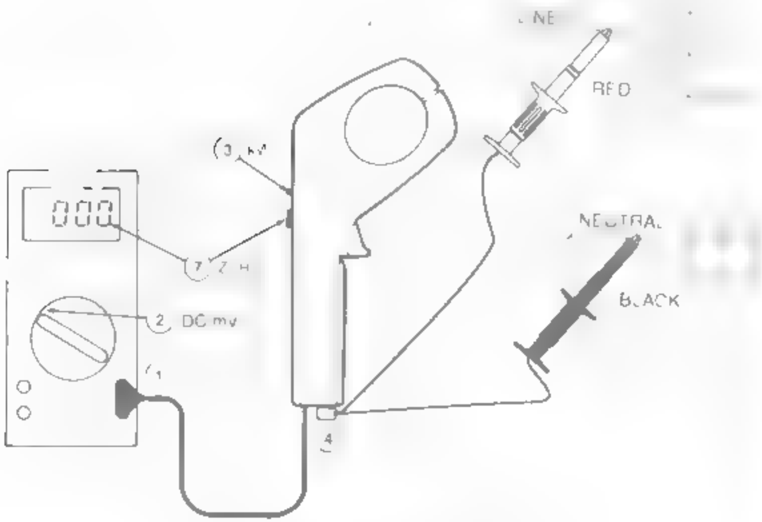



**Figure 2-5. kW ZERO Adjustment**

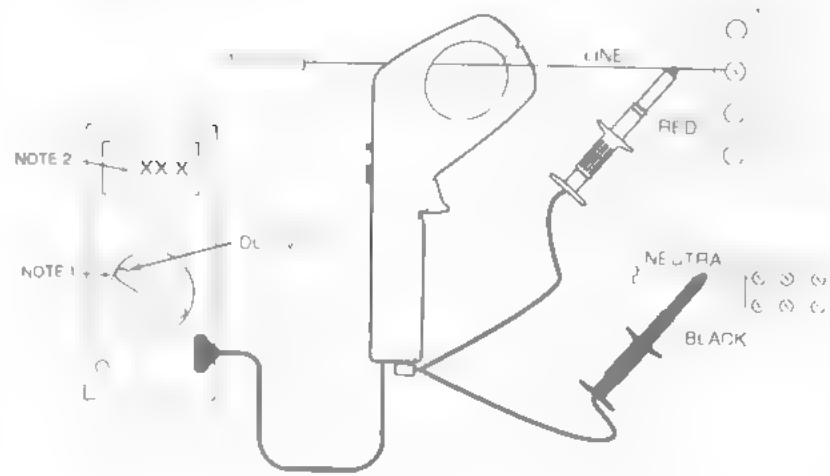




9. Squeeze the jaw trigger, and clamp the jaws around the line conductor. Verify that the current direction arrow is pointing toward the load. (See Figure 2-6.)

**WARNING**

**TO AVOID ELECTRIC SHOCK OR EQUIPMENT DAMAGE, DO NOT USE THE PROBE ON BARE CONDUCTORS.**




*NOTE[1]*

*Voltmeter function selection is the dc mV ⎓ because the probe output is dc when the kW function is selected.*

*NOTE[2]*

*If the reading is low or zero, check voltmeter function (see preceding note above). If the reading is negative, check for one of the following: Current direction opposite to arrow; voltage leads reversed, output lead to multimeter installed backwards; or load acting as a source*

**Figure 2-6. Single Phase 2-Wire Power Measurement**

10. Read the measured value in the voltmeter display. This value is the true power being delivered to the load. The jaws must be fully closed for a proper reading Best accuracy is obtained when the conductor is centered within the jaw aperture.

### Voltage Input Connections for Power Measurements

Use the diagrams (Figure 2-7) for input voltage connections:

### Output Connections for 3-Phase Power Recording

Since the probe's output in kW mode is dc millivolts, 3-phase power recording can be accomplished by using multiple probes and connecting their outputs in series so that they add algebraically For example, a 3-phase, 3-wire system can be monitored by two probes with their outputs connected in series so that the total output follows the equation $kW_T = kW_1 + kW_2$ as shown in Figure 2-7.

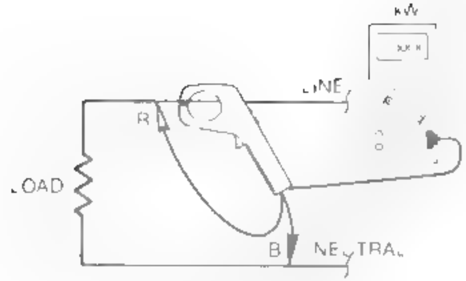
### Accuracy Enhancement Methods

The 80i-kW measures current at 1A or greater. Current below 1A can be accurately measured by looping the input wire through the jaws of the probe so that the sum of the amp-turns through the jaws is greater than 1A. The actual current is calculated by dividing the meter reading by the number of turns looped through the jaws. The same method is used to enhance the accuracy of low level power measurements

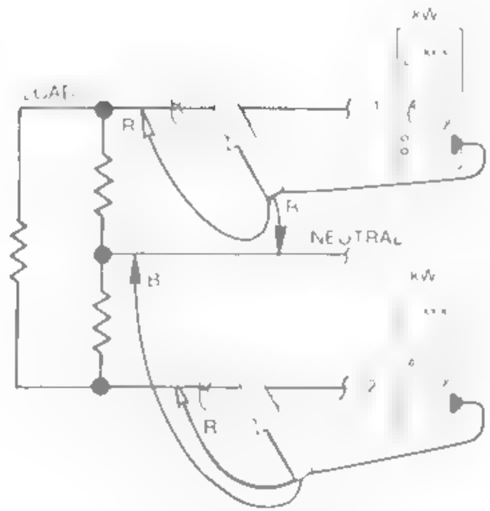
For low level dc measurements (below 5A), accuracy is improved by the dc ZERO adjustment procedure. This should be performed before each measurement. Check the ZERO adjustment if the current being measured has undergone a major change, i.e., from 100A to 1A, or if the measured current has changed polarity.








SINGLE-PHASE 2 WIRE

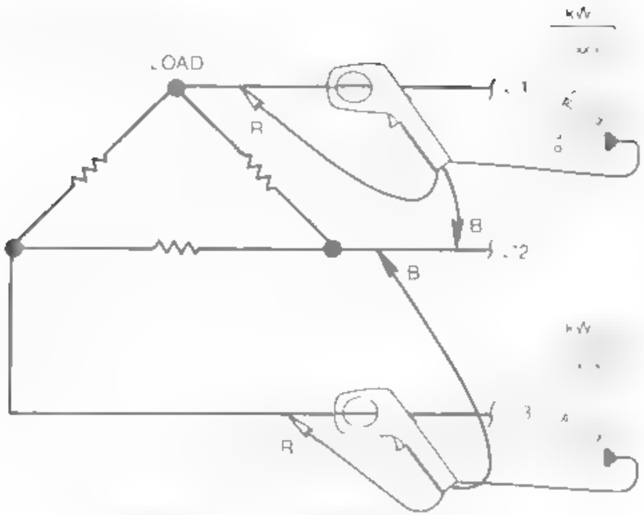



SINGLE-PHASE 3-WIRE
$kW_{TOTAL} = kW_1 + kW_2$

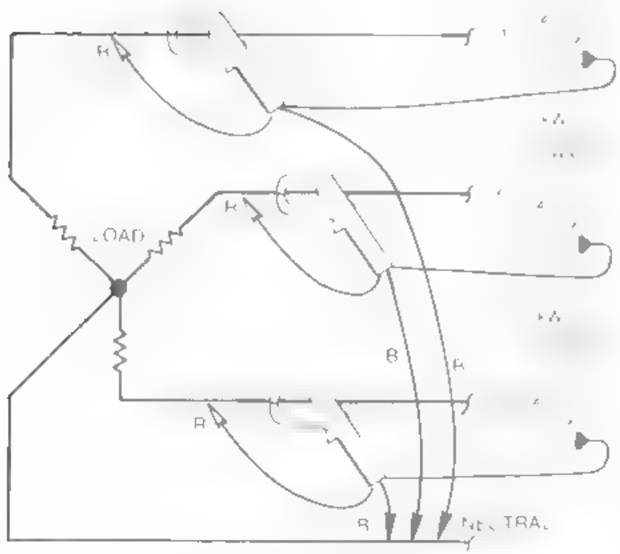
R = RED TEST LEAD
B = BLACK TEST LEAD

(continued on next page)

**Figure 2-7. Voltage Input Connections for Single-Phase and 3-Phase Power Measurements**




THREE-PHASE 3-WIRE DELTA or Y
$kW_{TOTAL} = kW_1 + kW_2$




THREE-PHASE 4-WIRE
$kW_{TOTAL} = kW_1 + kW_2 + kW_3$

**Figure 2-7. Voltage Input Connections for Single-Phase and 3-Phase Power Measurements (cont)**





### High Level Measurements

The accuracy of current measurements at levels greater than 600 amps is improved by using the typical performance graph (Figure 2-8) A correction factor, based on the graph data, is added to the measured value to reduce the total error.

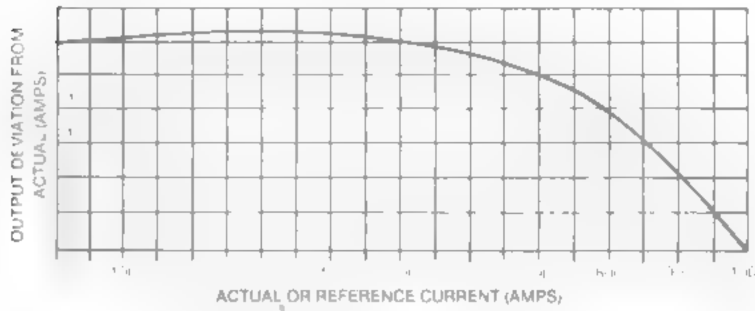



**Figure 2-8. 80i-kW Typical Performance in AC Current Mode**

### High Frequency Measurements

The accuracy of current measurements at frequencies greater than 100 Hz is improved by using the typical frequency response graph (Figure 2-9). A correction factor, based on the graph data, is added to the measured value to reduce the total error

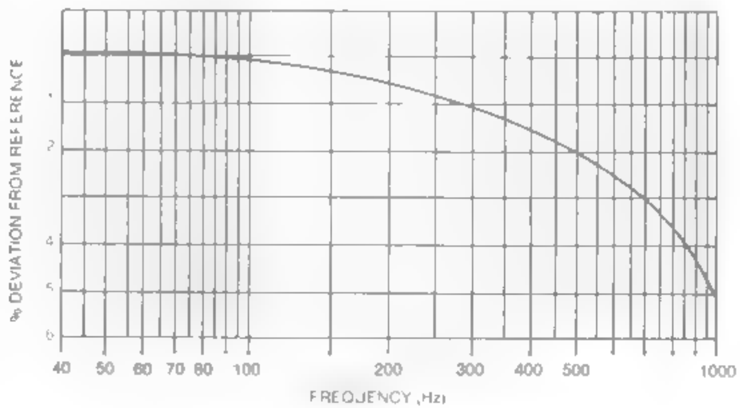



**Figure 2-9. 80i-kW Typical Frequency Response**

## Power Factor Calculations

In ac power distribution systems, "True Power Factor" is a ratio defined by the following equation:

$$\text{True Power Factor} = \frac{\text{True Load Power}}{\text{Apparent Load Power}} = \frac{\text{kW}}{\text{kVA}}$$

The true load power in kW can be measured by the 80i-kW probe connected to a multimeter set for dc millivolts as described in the measurement section of this manual. If the voltage or current is non-sinusoidal (distorted) the probe's internal circuit (in power mode) takes into account the distortion and harmonics that are within the probes bandwidth and crest factor limitations. In other words, no special requirements are necessary for the multimeter during the kW measurement because the multimeter is only measuring dc millivolts. When determining kVA however, the calculation requires separate measurements of ac voltage and ac current. When the 80i-kW is used to measure current in the AMP mode, the waveshape on the output to the multimeter follows waveshape on the conductor being measured in the jaws. If both the circuit voltage and circuit current are sine waves with little or no distortion, then the measurements for kVA can be made with an average responding multimeter or a true rms responding multimeter since both give the same readings for sine waves If either the ac voltage or ac current are significantly distorted however, the measurements will require a "true rms" responding multimeter for correct readings. Multimeters that have "true rms" capability are usually labeled on the front panel. Multimeters that are not labeled "true rms" or "t-rms" are likely to be average responding which means that they will read incorrectly (typically low) when waveforms are distorted. Read the following section describing the different types of loads before making measurements for kVA and power factor calculations.





## Load Types

In modern power distribution systems there are two types of loads: Linear and Non-Linear. For linear loads, the voltage and current are related by a linear (proportional) relationship, i.e., if the voltage is increased, the current will also increase by a proportional amount A linear load that is fed by a sinewave voltage will conduct a sinewave current. Typical examples of linear loads include resistive heaters, induction motors, incandescent lamps etc. The measurements necessary to calculate kVA can be made with multimeters that are either average responding or true rms responding. Inductive linear loads such as induction motors will produce a lagging power factor. The power factor for these loads can be corrected by adding capacitors in parallel with the load.

Non-Linear loads typically contain semiconductors or other devices which switch the current off and on abruptly during each cycle producing distorted (non-sinusoidal) currents containing harmonics. Typical examples of non-linear loads include, arc furnaces, variable speed motor drives, solid state (SCR) heating controls, certain types of fluorescent lighting, electronic and medical test equipment, electronic office machines such as personal computers, monitors, printers etc. The measurements necessary to calculate kVA for non-linear loads require a true rms multimeter for accurate readings.

Before attempting to make measurements, conduct a visual survey of the loads present If no electronic or other non-linear loads are identified, read the paragraph titled "Power Factor Calculations for Traditional Linear Loads." If the visual survey indicates the presence of non-linear loads or other sources of non-sinusoidal currents, use the methods described in the paragraph titled "Non-Linear Load Measurements."

### POWER FACTOR CALCULATIONS FOR TRADITIONAL LINEAR LOADS

Linear electrical loads that are supplied by sine wave voltages produce sine wave currents. When both the current and voltage are sine waves and no harmonics are present, the mathematical formula for power factor is reduced to a special case called "displacement power factor," i.e., for sine waves

True Power Factor = Displacement Power Factor

$$= \frac{kW}{kVA}$$

$$= \cos\theta$$

Where θ is the phase angle between the fundamental voltage and the fundamental current. This is the quantity utilities typically measure when they refer to "power factor."

The displacement power factor will have a value of 1.0 for a purely resistive load where the voltage and current are in phase and the kW equals the kVA. Loads that have an inductive component will cause the current to lag the voltage and the kVA will be greater than the kW causing the displacement power factor to be less than 1.0. A typical range of displacement power factor values for a combination of industrial loads would be 0.5 (50%) to 0.9 (90%).

The inductive current associated with low displacement power factor is generally undesirable because it does no useful work and it causes the total current to increase, thereby using up the capacity of the power distribution system. Electrical utilities often charge a penalty for loads that have displacement power factors that fall below a predetermined level. The inductive current that lowers the displacement power factor can be reduced or eliminated by adding capacitors in parallel with the load. This process is called "power factor correction." The process involves first measuring the displacement power factor and then choosing the correct capacitance value from selection tables provided by the capacitor manufacturers. The 80i-kW and a suitable voltmeter can be used to determine the displacement power factor as follows.

1. Use the voltmeter to measure the load voltage.
2. Use the 80i-kW in the AMP mode to measure the load current.
3. Use the 80i-kW in the kW mode to measure the true load power.
4. Use the formulas below to calculate the displacement power factor from the measured data. (See example that follows)





Displacement Power Factor = $\frac{kW}{kVA}$, (sine waves only)

kW = total power in all three phases as described in fig 2-7.

kVA = $\frac{V*I}{1000}$, (single phase)

kVA = $\frac{1.732*V*I}{1000}$, (3 phase, 3 wire, assumes balanced load, voltage measured phase-to-phase)

kVA = $\frac{3*V*I}{1000}$, (3 phase, 4 wire, assumes balanced load, voltage measured phase-to-neutral)

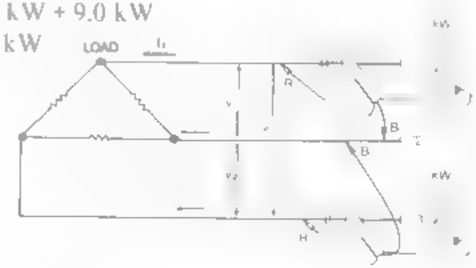
Example.

A 50 hp induction motor is being supplied by a 3 phase, 3 wire line. What steps are necessary to determine the displacement power factor?

Solution

1. The phase-to-phase voltages are measured with the voltmeter while the load is on and recorded as follows
   $V_{1-2}$ = 491 v
   $V_{2-3}$ = 491 v
   $V_{1-3}$ = 491 v
2. The phase currents are measured with the 80i-kW in the AMP mode and recorded as follows
   I 46.9 A
   I 47.0 A
   I 47.1 A
3. The total load power is determined by making two measurements with the 80i-kW in kW mode and adding the two readings as follows. (See Fig 2-7, pg 2-14)

   kW total = $kW_1 + kW_2$
   22.6 kW + 9.0 kW
   = 31.6 kW



4. The apparent power in kVA is calculated from the measured data taken in steps 1. and 2. Since the phase currents are not exactly equal, an average is used

$$kVA = \frac{(1.732)(491)(47.0)}{1000}$$
$$= 39.96\ kVA$$

5. The displacement power factor is calculated from the kW found in step 3. and the kVA found in step 4.

$$\text{Displacement Power Factor} = \frac{kW}{kVA} = \frac{31.6}{39.96} = 0.79 \text{ or } 79\%$$

Once the power factor is known, the size, ratings, and location of the correction capacitors can be determined from application notes supplied by the capacitor manufacturers. A partial list of these application notes is given below for reference:

- "Savings for Industry" Cornell Dubilier Electronics, Inc. New Bedford, MA
- "Gematic Power Capacitors" General Electric Co. Hudson Falls, NY
- "Power Factor Correction for Plant Engineers" Sprague Electric Co. North Adams, MA
- "Power Factor Capacitors Pocket Reference Guide" Westinghouse Electric Co. Bloomington, IN
- "Aero Var Power Factor Correction Capacitors," Aerovox Inc., New Bedford, MA.

## Non-Linear Load Measurements

### DETECTING DISTORTION AND HARMONICS

The distortion and harmonics caused by non-linear loads can occur in either voltage or current waveshapes. In ac power distribution systems with electronic or other non-linear loads, distortion is more likely in the





current waveshape than in the voltage waveshape. This occurs because the current waveshape is primarily determined by the load, and the voltage is primarily determined by the generator.

Power frequency current with distortion or harmonics can be measured directly with the 80i-kW. When the probe's function switch is set to the AMP mode, the probe's output voltage follows the waveshape of the current up to the probe's bandwidth limit of approximately 3 kHz.

The current waveshape can be viewed directly by connecting the probe's output to the input of an oscilloscope that has sufficient sensitivity. This is the most direct method for detecting distortion and harmonics.

If an oscilloscope is not available, an alternative method can be used. This method uses two different types of multimeters, one that has an ac converter that responds to the average value of the waveshape and one that responds to the true rms value of the waveshape. Examples of multimeters that are average responding include Fluke models 8020, 8021, 8022, 8024, 20 Series, and 70 Series. Examples of multimeters that respond to the true-rms value include Fluke models 87, 8026, 8050, 8060, and 8062.

If a multimeter model or equivalent of each type is available, use the 80i-kW to make two measurements of the same current. First use the average responding multimeter; then use the true rms responding multimeter. Record the readings and compare them. If the readings are different by a significant amount, it is very likely that distortion and harmonics are present in the current waveshape. The larger the difference in readings, the greater the amount of distortion. If the readings are the same, or nearly so, it is much less likely that harmonics are present. (See the reference below for more information.)

NOTE

*It is assumed that the multimeters are calibrated properly and that the current is constant during the measurement period. If the load changes between readings, the results are invalid.*

## POWER FACTOR CALCULATIONS FOR NON-LINEAR LOADS

The definition of true power factor for nonlinear loads is:

$$\text{True Power Factor} = \frac{\text{True Load Power}}{\text{Apparent Load Power}} = \frac{kW}{kVA}$$

The 80i-kW can be used to measure true load power as described in the previous section. The formulas for kVA given in the previous section may also be used except that when non-linear loads and harmonics are present, the calculations for kVA require measurements of true rms voltage and true rms current. Therefore, a true rms multimeter must be used for these measurements.

Harmonics tend to reduce the true power factor because they typically increase the true rms current and kVA but not the kW. This is due to the fact that harmonics are multiples of the fundamental frequency and therefore cannot transfer true power at the fundamental frequency because true power transfer takes place only when voltage and current are at the same frequency.

The degradation in true power factor due to harmonics is not caused by a phase shift between the fundamental voltage and current as it is in the case of linear inductive loads. In general, when significant harmonics are present, the true power factor is not equal to either the displacement power factor or cos θ and therefore, the true power factor degradation due to harmonics cannot be corrected by adding capacitors in parallel with the load. In most cases, parallel capacitors alone will make the situation worse because they provide a low impedance path for the harmonic currents thereby increasing the kVA. Capacitors can also interact with circuit inductance causing a resonance condition which can increase currents to dangerous levels. When the load consists of a combination of linear and non-linear devices, a complete harmonic analysis should be made before adding capacitors, reactors, filters, etc.

Reference: "Understanding Harmonics in Power Distribution Systems" (Fluke Literature #B0194A)



# Section 3
# Theory of Operation

A magnetic field is generated around a current-carrying conductor with a strength and direction directly proportional to the magnitude and polarity of the current (Ampere's law). The 80i-kW concentrates that field in a magnetic core built into its jaws.

The field is measured with two Hall-effect devices mounted in narrow airgaps in the core. A Hall-effect device is a small semiconductor that produces an output voltage directly proportional to the strength and direction of a magnetic field into which it is placed.

The voltage output of the 80i-kW is an accurate analog voltage equivalent to the ac, dc, or composite (ac-on-dc) current in the conductor, amplified and scaled for 1 mV per ampere.

The watt function uses the same Hall-effect devices configured into analog multiplier circuits. The voltage input signal is transformer coupled to one side of the Hall devices. The output then becomes the cross-product multiplication of the voltage times the current, which is proportional to true power.

# Section 4
# Maintenance

WARNING

**THESE SERVICING INSTRUCTIONS ARE FOR USE BY QUALIFIED PERSONNEL ONLY. TO AVOID ELECTRIC SHOCK, DO NOT PERFORM ANY SERVICING PROCEDURES UNLESS YOU ARE QUALIFIED TO DO SO. READ THE INFORMATION TITLED "OPERATOR SAFETY" AT THE BEGINNING OF SECTION 2 BEFORE PROCEEDING.**

## SERIAL NUMBER LOCATION

The seven-digit serial number is located on the inside surface of the battery door and is visible when the battery door is open. Use the battery installation procedure that follows to locate the serial number.

## BATTERY INSTALLATION

The 80i-kW requires one 9V battery, NEDA Type 1604A. The following procedure instructs you on how to install the battery:

1. Disconnect the probe from all other circuits or equipment, and remove the test leads.

2. Place the probe on a clean work surface and orient the probe so that it lies on its back with the jaws pointing upward.

3. Insert the tip of a narrow flat-bladed screwdriver, into the slot located just behind the jaw trigger. (See Figure 4-1.)

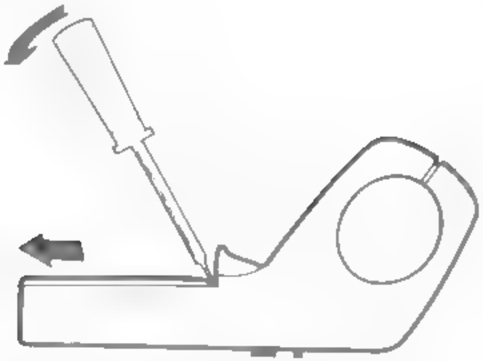


Figure 4-1. Battery Removal

4. Twist the screwdriver ¼ turn to snap open the battery door.

5. Slide the door open, and replace the battery.

6. Snap the door shut, and test the battery as follows:

   Move the function switch from OFF to either AMPS or kW. The ON LED should be illuminated, indicating that the battery voltage is within operating limits.

## CLEANING AND STORAGE

Clean the mating surfaces of the core at regular intervals. Apply a light coating of dripless oil to prevent corrosion. Use a soft cloth dampened in a mild solution of detergent and water to clean the 80i-kW. Do not use solvents. If the probe is not to be used for periods of longer than 60 days, remove the battery and store it separately

## CALIBRATION

Complete calibration of the 80i-kW is done by adjusting the five potentiometers shown in Figure 4-2. The adjustments are made through openings in the case, which are exposed by removing the main decal.

Replacement decals are available through the Fluke Parts Department. Order part number 845094.





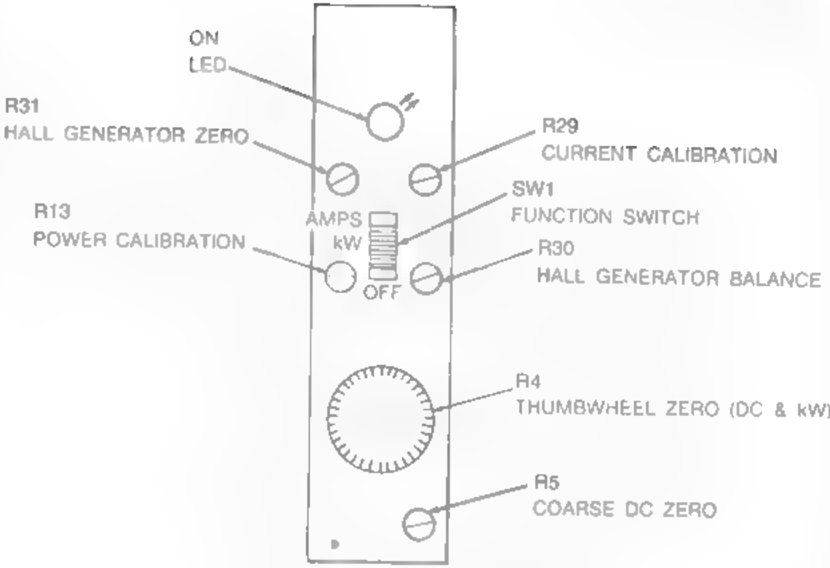



Figure 4-2. Location of Adjustments

### Equipment Required for Calibration

Table 4-I lists the equipment required to perform the calibration adjustment procedures.

### Step-by-Step Adjustment Procedure

*NOTE*

*The following procedures are interactive and must be performed in the order given.*

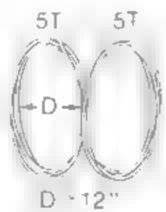
### LOW BATTERY INDICATOR CIRCUIT CHECK

Perform the low battery indicator circuit check as follows.

1. Open the battery door and remove the battery. (See Figure 4-1 for the location of the battery door.)

2. Connect the output of the dc/ac calibrator to the battery terminals Carefully observe polarity

Table 4-1. Calibration Equipment

| INSTRUMENT TYPE | RECOMMENDED MODEL |
|---|---|
| DC/AC Voltage Calibrator | Fluke Model 5100B |
| Transconductance Amplifier | Fluke Model 5220A |
| AC Voltage Calibrator with phase lock input (2 required) | Fluke Model 5200A |
| AC Power Amplifier | Fluke Model 5205A or 5215A |
| Digital Multimeter (with ac coupling on ac voltage ranges) | Fluke Model 8050A |
| Digital Phase Meter (see note) | Krohn-Hite 6500 |
| Oscilloscope Probe (X100) | Tektronix Model P6009 or Equiv |
| Non-Inductive Shunt | T & M Research Products, Inc. |
| Small Insulated Screwdriver | Spectrol |
| Foil Capacitor, 0.5 µF | |
| Decade Resistor 0-100 kΩ | |
| Switch, DPDT, low voltage | |
| Magnet Wire Coil 10 turns (2 x 5) of #12 single conductor shaped in a butterfly configuration of two 12" diameter coils (10 turns, 18 in diameter is an acceptable alternative. |  5T 5T D D = 12" 10-TURN BUTTERFLY COIL |
| Magnet Wire Coil 50 turns of #10 single conductor copper wire 3.5 inch diameter wound in a 270° toroid configuration |  50 TURN TOROID COIL |

NOTE

A dual-trace, 2-channel oscilloscope with a differential input may be substituted for the digital phase meter (See Figure 4-4.)

3. Set the calibrator output to +9.0V dc, and set the probe's function switch to "kW." Verify that the power ON LED on the probe is illuminated.

4. Decrease the calibrator output voltage to +6 0V dc, and verify the probe's LED is off.

5. Increase the voltage to +6.4, and verify that the LED is ON.





6. Remove the calibrator connections, and install a fresh 9V battery.

7. Snap the battery door shut. The probe is now ready for calibration.

## INITIAL DC ZERO ADJUSTMENT

Perform the initial dc ZERO adjustment as follows.

1. Remove the main decal to gain access to the calibration adjustments (See Figure 4-2.)

2. Connect the probe output cable to the multimeter volts input. Observe polarity.

3. Turn the multimeter on and set the range and function to 200 mV dc.

4. Set the probe function switch to the center (kW) position.

5. Center the thumbwheel ZERO control

6. Adjust the coarse dc ZERO trim pot R5 for a 0.0 ± 0.5mV dc reading on the multimeter

7. Set the probe function switch to the AMP position.

8. Adjust the Hall generator zero trim pot R31 for a 0.0 mV ± 0.5 mV dc reading on the multimeter.

## HALL GENERATOR BALANCE ADJUSTMENT

Perform the Hall generator balance adjustment as follows.

1. Connect the 10-turn magnet wire coil to the output of the transconductance amplifier

2. Connect the ac/dc calibrator to the transconductance amplifier input, and set the controls to generate 10 amps ac at 50 or 60 Hz. This produces 100 amp-turns in the center conductor bundle.

3. Set the multimeter function and range to accommodate a display of 100 mV ac.

4. Clamp the probe around the center conductor (Figure 4-3) and move the probe alternately back and forth to position the conductor first at the top and then at the bottom of the aperture. Note the readings and adjust the Hall Generator balance R30 until the top and bottom readings are equal ± 0.3 mV ac

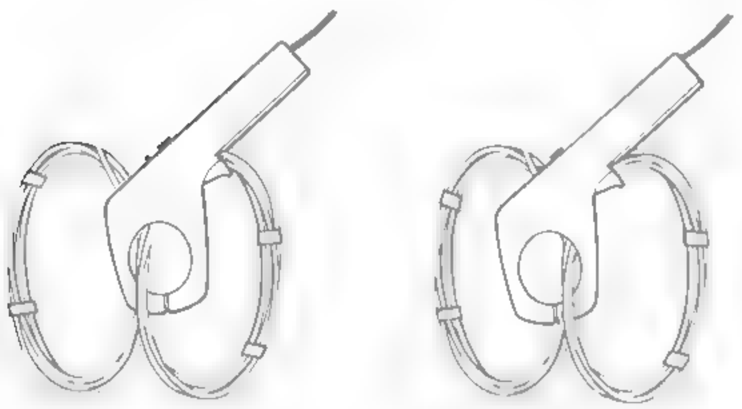


**Figure 4-3. Conductor Postions for Hall Generator Balance Adjustment**

5. Remove the probe from the coil and set the calibrator controls to STANDBY.

6. Set the multimeter function and range to accommodate a display of 100 mV dc.

7. Adjust the Hall generator zero trim pot R31 for a 0.0 mV ± 5 mV dc reading on the multimeter.

8. Disconnect the 10-turn coil from the transconductance amplifier output. This completes the Hall generator balance adjustment.





## CURRENT CALIBRATION

Perform the current calibration as follows:

1. Connect the output of the ac calibrator to the input of the transconductance amplifier.

2. Connect the 50-turn toroid coil to the transconductance amplifier output, and set the calibrator controls to generate a current of 10 amps at 50 or 60 Hz. This produces 500-amp turns in the center conductor bundle

3. Set the multimeter function and range to accommodate a display of 500 mV ac.

4. Clamp the probe around the center conductor bundle, and support the probe so that the conductor bundle is at the center of the jaw aperture.

5. Adjust the current calibration trim pot R29 until the multimeter reads as close as possible to 500 mV ac.

6. Remove the probe from the coil, and set the calibrator controls to standby This completes the current calibration.

## FINAL DC ZERO ADJUSTMENT

Perform the final dc ZERO adjustment as follows:

1. Set the multimeter function and range to accommodate a display of 100 mV dc.

2. Set the probe function switch to the kW (center) position.

3. Rotate the thumbwheel ZERO control to the maximum clockwise and the maximum counterclockwise positions. Record the readings at each position. The total range should be 20 ±2 mV dc.

4. Calculate the electrical center and set the thumbwheel ZERO to this reading.

5. Adjust the COARSE ZERO trim pot, R5, for an output reading of 0.0 mV ± 0.1 mV dc.

6. Set the probe function switch to the AMP (top) position.

7. Adjust the Hall generator ZERO, R31, for an output reading of 0.0 mV ± 1 mV dc. This completes the final dc zero adjustment.

## POWER CALIBRATION

### DANGER

**THE EQUIPMENT DESCRIBED IN THIS PROCEDURE CAN GENERATE LETHAL VOLTAGES. TO AVOID ELECTRIC SHOCK, DO NOT PERFORM ANY PART OF THIS PROCEDURE UNLESS YOU ARE QUALIFIED TO DO SO. DO NOT ATTEMPT TO ENERGIZE ANY OF THE DESCRIBED EQUIPMENT UNLESS YOU ARE ACCOMPANIED BY A SECOND PERSON WHO IS QUALIFIED TO ASSIST IN CASE OF AN EMERGENCY.**

1. Connect the test setup shown in Figure 4-4. Use caution in the following areas.

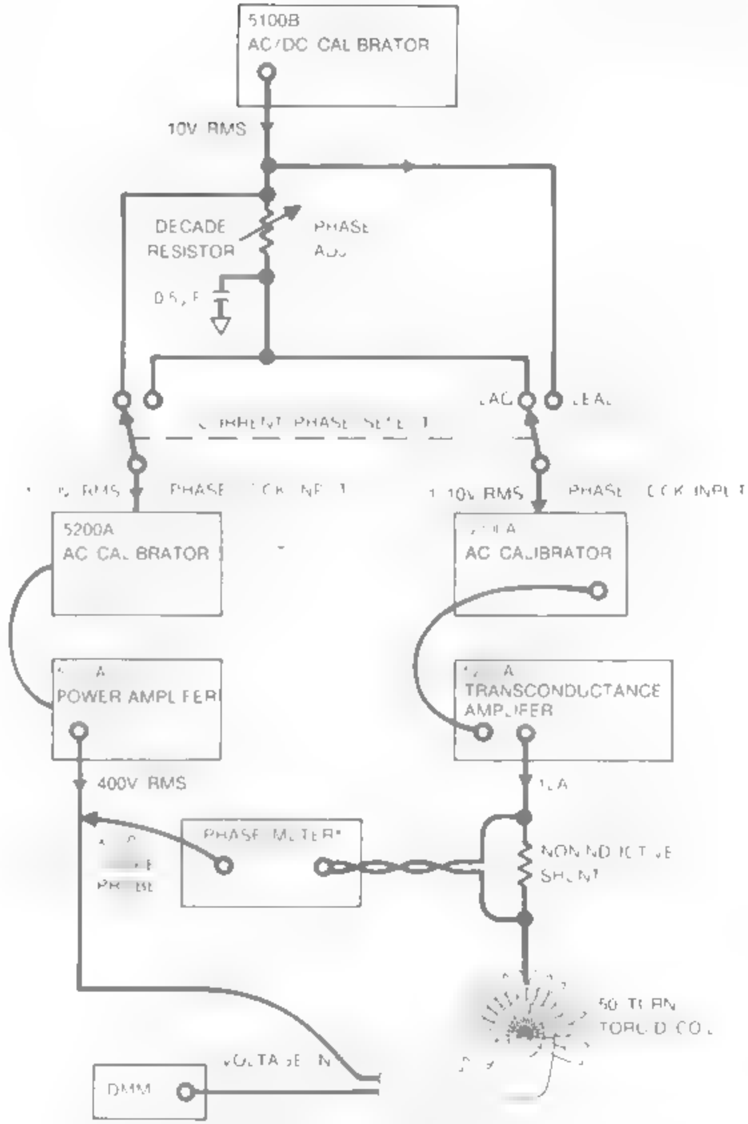
   a. Carefully secure the output cable of the power amplifier so it cannot come into contact with any foreign objects.

   b. Verify that the OUTPUT LOW binding post is connected to the earth ground binding post on the front panel of the power amplifier.

   c. The transconductance amplifier's input-low and output-low terminals must not be connected together. If the output is grounded by the phase meter (or oscilloscope), the input must float.








*A dual trace 2 channel oscilloscope with a differential input may be substituted for the digital phase meter. If the oscilloscope is used connect the differential input across the noninductive shunt. This will minimize ground loop problems.

**Figure 4-4. Test Set Up for Power Calibration**

d. The signal connection cable between the noninductive shunt and the phase meter is a potential source of significant error. Use coax or tightly twisted pair to avoid a loop that could pick up a magnetic field, thereby producing an error at the phase meter input.

2. Apply line power to all equipment and allow sufficient warm-up time to obtain stable readings.

3. Set the multimeter function and range to display a reading of 200 mV dc.

4. Perform the phase meter ZERO procedure. (Consult the manufacturer's instructions.)

5. Set the probe function switch to kW.

6. Set the controls on the AC/DC calibrator to: 10V ac, 50 or 60 Hz, OPERATE.

*NOTE*

*The most stable results are usually obtained if the test frequency is different than the line frequency, i.e., if the line frequency is 60 Hz, the test frequency should be 50 Hz and vice versa.*

7. Set the decade resistor to minimum value.

8. Set the CURRENT PHASE SELECT switch to LAG.

9. The AC Calibrator shown on the right hand side of Figure 4-4 establishes the amplitude, phase, and frequency of the current. On this unit, set the controls as follows:

| | |
|---|---|
| VOLTAGE RANGE: | 10V |
| VOLTAGE: | 10.0000V |
| FREQUENCY RANGE: | 100 Hz |
| FREQUENCY: | 50 or 60 Hz (use same frequency as Step 6) |
| PHASE LOCK: | ON |
| MODE: | OPERATE |





10. On the transconductance AMPLIFIER, set the mode switch to OPERATE.

**DANGER**

**IN THE NEXT STEP, A LETHAL VOLTAGE WILL BE PRESENT AT THE OUTPUT OF THE POWER AMPLIFIER. TO AVOID ELECTRIC SHOCK AND/OR EQUIPMENT DAMAGE, VERIFY THAT ALL CONNECTIONS TO THE POWER AMPLIFIER OUTPUT HAVE BEEN MADE IN A SAFE MANNER BEFORE PROCEEDING.**

11. The AC Calibrator shown on the left hand side of Figure 4-4 establishes the amplitude, phase, and frequency of the voltage. On this unit, set the controls as follows in the order given:

| | |
|---|---|
| VOLTAGE RANGE: | 1000V |
| VOLTAGE: | 400V |
| FREQUENCY RANGE: | 100 Hz |
| FREQUENCY: | 50 or 60 Hz (use same frequency as step 6) |
| PHASE LOCK: | ON |
| MODE: | OPERATE |

12. Remove the 80i-kW from the 50-turn coil and adjust the thumbwheel ZERO to obtain a multimeter reading as close as possible to 0.0 mV dc.

13. Clamp the 80i-kW around the 50-turn coil and support the probe so that the center conductor bundle is approximately in the middle of the jaw aperture.

14. Adjust the decade resistor until the phase meter reads as close as possible to 0.0°. At this point, the 80i-kW should be measuring 500A, 400V at a power factor of one. This corresponds to 200 kW.

15. Adjust the power calibration trim pot R13 until the multimeter reads as close as possible to 200.0 mV dc.

16. Set all calibrator mode controls to STANDBY and remove the 80i-kW from the 50-turn coil. This completes the calibration procedure.

## TROUBLESHOOTING

Before using the troubleshooting guide (Table 4-2) for the 80i-kW, check for obvious problems such as function switch position, low batteries, loose or incorrect connections on the 80i-kW or peripheral equipment, poor closing of jaws, or foreign material in jaws. In addition, check the function switch selection on the multimeter. For power measurements (kW) or dc current, the multimeter function should be set for dc. For ac current, the correct selection is ac.

The troubleshooting guide component reference designators correspond to the 80i-kW schematic located in Section 6. Symptoms are given in the left-hand column, and possible causes are given in the right-hand column.

### CAUTION

**If it is determined that the core or Hall generator sensors are defective, the entire assembly must be returned to a Fluke service center. Hall generators are not field replaceable parts.**





**Table 4.2. 80i-kW Troubleshooting Guide**

| SYMPTOM | POSSIBLE CAUSE |
|---|---|
| LED does not illuminate when unit is switched ON | Low battery<br>Q1, Q2, CR1, CR2, CR5, SW1 |
| Short battery life | Q1, Q2, CR5, U1, U2 |
| Output will not zero (amps position) | Hall Generator A<br>Hall Generator B<br>Coarse zero pot R5<br>(not properly adjusted) |
| (watts position) | CR4, Q3, Q4, U1, U2 |
| No output | U1<br>Broken wire in output cables |
| (watts position) | U2, T101, SW1-3 |
| Current readings out of tolerance | R29 out of calibration |
| Power readings out of tolerance | R13 out of calibration |
| Reversibility errors on dc current | Unit not properly zeroed |
| Large errors due to conductor positioning in the aperture | R30 out of calibration |

# Section 5
# Replacement Parts and Service

## INTRODUCTION

This section contains maintenance information for the 80i-kW. Included is a parts list and service center information.

## HOW TO OBTAIN PARTS

The following parts listed in Table 5-1 are available from the Fluke parts department. Refer to the table for part description and Fluke part number. Table 5-2 contains remaining parts by reference designator number. These parts can be obtained from a local electronic parts supplier.

## SERVICE CENTERS

For service center information use the phone number listed below that applies to you. Additional warranty service center information is contained in the product warranty located on the inside cover of this manual

800-426-0361 in most of U.S.A.
206-356-5400 from AK and WA
306-356-5500 from other countries

Table 5-1. List of Replaceable Parts

| ITEM | FLUKE PART NUMBER |
|---|---|
| Voltage Test Leads | 845115 |
| Safety Alligator Clip, Red (see note) | 927582 |
| Safety Alligator Clip, Black (see note) | 927579 |
| Control Panel Decal | 845094 |
| Rear Input Decal | 856067 |
| Core Hinge Insulator | 857177 |
| Carrying Case Assembly | 856070 |

**NOTE**

The safety alligator clips are also available as part of multimeter accessory test lead set Model TL20.





Table 5-2. Reference Parts List

| REFERENCE DESIGNATION | DESCRIPTION |
|---|---|
| A1 | ANALOG PCB |
| R12 | RES., SMD, 34 8K |
| R2, R33 | RES., SMD, 5 11K |
| R1, R3 | RES SMD 47.5K |
| R7 | RES , SMD 200K 5% |
| R8 | RES SMD 1 2 MEG 5% |
| R9, R10, R24, R32, R34, R35, R39 | RES SMD. 10K |
| R11 | RES SMD, 90 9K |
| R14 | RES , SMD, 182K |
| R15 | RES , SMD, 40 2K |
| R16 | RES , SMD 64 9K |
| R17 | RES SMD 45 3K |
| R18 R19 | RES SMD. 13 7K |
| R20 | RES SMD 2K |
| R21, R22 | RES SMD 9 09K |
| R23 | RES , SMD, 9 1K 5% |
| R25 | RES., SMD, 18.2K |
| R26 R27 | RES , SMD 20 OHMS 5 |
| R28 | RES , SMD 357 OHMS |
| R37 | RES , SMD 100 |
| R38 | RES SMD, 1K |
| R40 | RES SMD, 1.8K, 5% |
| R4 | POT 20K THUMB ZERO |
| R5 R29 R31 | POT , TRIM 20K, MULTI-TURN |
| R6 R13, R30 | POT , TRIM SMD, 20K 3/4 TURN |
| R300 | THERMISTOR, RECT , POSITIVE, 1K OHM 40% |
| C1 C2 | CAP SMD. 01uF, 1%, NPO 1812 SIZE |
| C3, C7 | CAP TANTALUM 4.7uF 16V |
| C4 | CAP ELECT RAD , 22uF, 35V |
| C5, C6 | CAP CER MONO , 0 1uF 50V |
| C8 | CAP , TANTALUM 1.0uF 16V |
| CR1, CR2 | DIODE SMD (SOT-23) 1N914 |
| CR3 | L.E D HLMP-4700 |
| CR5 | DIODE 1N4003 |
| CR4 | VOLTAGE REF , 1 2 VOLT ICL8069 |
| SPA | SPACER L E D , (BIVAR 455-300) |
| Q1, Q2 Q3 | TRANSISTOR, SMD (SOT-23), 2N4124 NPN |
| Q4 | TRANSISTOR SMD (SOT-23), 2N4126, PNP |

Table 5-2. Reference Parts List (cont)

| REFERENCE DESIGNATION | DESCRIPTION |
|---|---|
| U1 | QUAD OP-AMP SMD TLC27M4BCD |
| U2 | DUAL OP-AMP SMD LM358M |
| U3 | REGULATOR SMD 6 VOLT, TK11460M (TOKO) |
| FLT1 | "T" RF FILTER MURATA DSS310-55-Y5S-223S |
| T101 | VOLTAGE INPUT TRANSFORMER ASSEMBLY |
| SW1 | SWITCH SLIDE 4P3T |

ALL RESISTORS ARE METAL FILM 1% TOLERANCE, 100PPM/C, SIZE 0805 UNLESS OTHERWISE NOTED

ALL SURFACE MOUNT COMPONENTS ARE IDENTIFIED WITH "SMD"





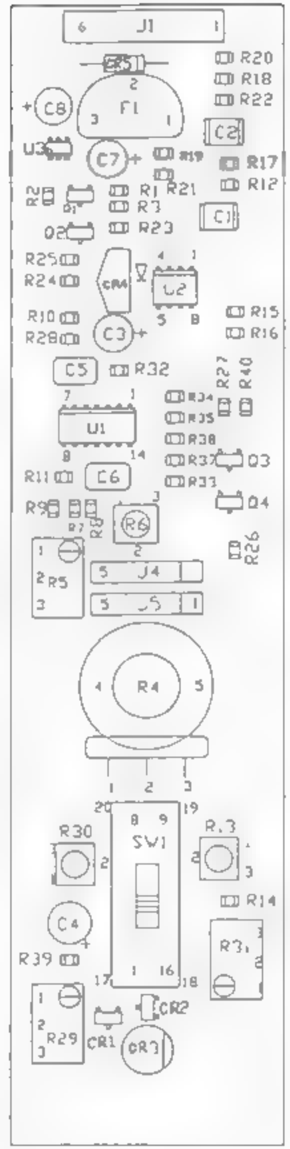
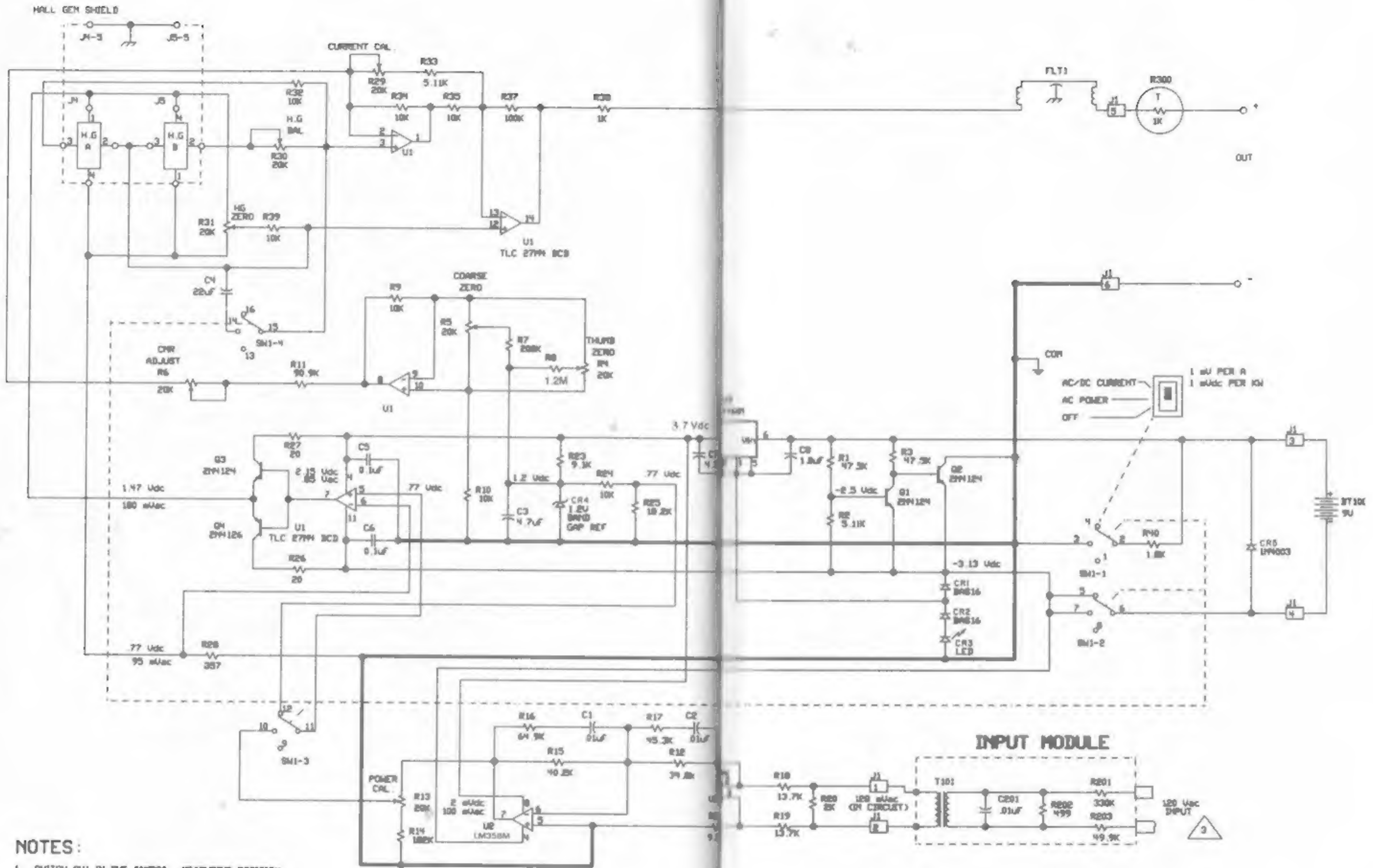



Figure 5-1. Component Locations

# Section 6
# Schematic Diagram

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## NOTES:

1. SWITCH SW1 IN THE "AMPS" MEASURING POSITION.
2. ALL VOLTAGES REFERENCED TO COM (- OUTPUT LEAD) UNLESS OTHERWISE INDICATED.
3. dc VOLTAGES ARE MEASURED WITH THE SWITCH SW1 IN THE "AMPS" POSITION. ac VOLTAGES ARE MEASURED WITH THE SWITCH IN THE "WATTS" POSITION, 120 Vac INPUT, AND NO CURRENT THROUGH THE APERTURE.

**Figure 6-1. 80i-kW Schematic**